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IMPROVING RESILIENCE TO STORM SURGE HAZARDS

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ABSTRACT

IMPROVING RESILIENCE TO STORM SURGE HAZARDS: ASSESSING RISK THROUGH WAVE SIMULATIONS, SHORELINE MODELLING AND FIELD OBSERVATIONS

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Winds, waves and tides associated with storms are capable of causing severe damage to coastal property and infrastructure. Locations that are prone to erosion and inundation first require an accurate assessment of risk before deciding the most cost effective mitigation option. This research aims to produce probabilistic assessments of the coastal erosion and inundation risks associated with storms, particularly for coincident or clustered events, thereby helping to strengthen the resilience of coastal communities.

Coastal erosion and inundation hazard is modelled in this study by simulations of realistic storm condition forcing (waves and tides) through a morphodynamic model to calculate return periods for maximum extent of shoreline retreat. This approach of estimating erosion return periods is superior to the assumption that the most energetic storm causes maximum erosion. The methodology is demonstrated at Old Bar, NSW, which us currently an erosion hotspot. The model will also be applied for the metropolitan Adelaide beaches. These sites were selected to test the methodology for a span of geographic conditions in terms of storm climate and deep-water wave exposure, working towards developing this method into a transportable framework applicable to other coastal areas.

Desktop and field assessments of each site were conducted to document geomorphic and sediment characteristics to inform shoreline modelling. Having established the historical framework at each location, multivariate statistical analysis of wave (buoy or hindcast models) and tides for peak storm events has allowed for the synthesis of realistic future conditions. This complex sequencing of cycling between accretion and erosion incorporating cross-shore and alongshore sediment transport has been estimated using a probabilistic shoreline translation model. Here, model outputs for Old Bar are illustrated, which indicate a complex response over decadal time frames. Further work will then assess risk to infrastructure based on the most probable envelope of shoreline position. This information can then be used to inform coastal management strategies.

INTRODUCTION

Relied upon heavily by coastal management agencies, beach morphodynamic models are a valuable tool for understanding the past, present and future evolution of sedimentary shorelines. Accuracy in these beach morphodynamic models is constrained by the proper characterization of the corresponding hydrodynamic processes that are directly responsible for mobilizing sediment and changing the configuration of the shoreline. Further, decadal shifts in wave climate may lead to complex sequences of erosion and accretion at a given site.

Detailed description of the nearshore mean water levels, waves and the associated littoral currents is required as forcing conditions used within the morphodynamic models. Two common techniques for this purpose are fully coupled hydrodynamic and morphodynamic models, (e.g. Delft3D), or pre-calculated wave lookup tables built from stationary wave model simulations, (e.g. SWAN), which are then used to force morphodynamic models based on the CERC longshore sediment transport equation. The lookup table approach is attractive owing to its ability to be adapted in a probabilistic framework, often desired by coastal managers. The coupled models are too slow to run the multiple realisations of the wave climate required to generate robust statistical measures of the beach response to changes in wave climate.

This study presents a framework based on modelling nearshore wave transformation with the SWAN model and creation of wave lookup tables for beach morphodynamic modelling at two study sites, Old Bar, NSW, an erosion hotspot at present (figure 1), and the Adelaide metropolitan beaches. The results for Old Bar are the focus here. A shoreline evolution model is developed using the EVO model (Teakle, 2013), which combines both cross-shore (Miller, 2004) and longshore sediment transport processes. The former process is commonly associated with episodic erosion due to storm events; the latter is associated with longer term erosion or accretion at a given location. We document the sensitivity of the models to different realisations of statistically similar wave climates, using the same initial conditions.

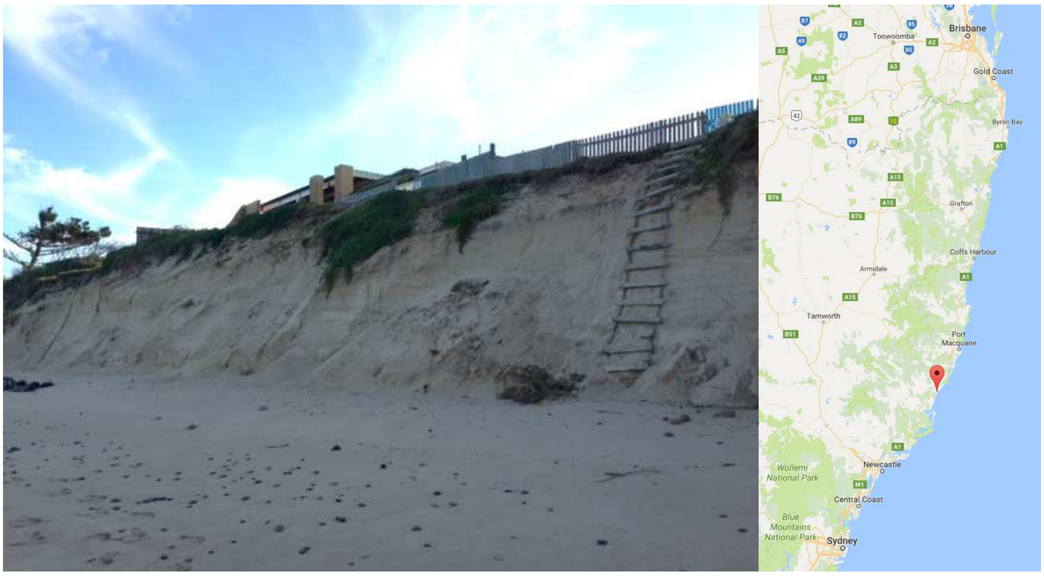

Figure 1. Beach erosion at Old Bar, NSW, June 2015.

METHODS

WAVE MODELLING

Wave data and beach profile data were combined to build a SWAN model for nearshore waves (figure 2 &3), based on a statistical representation of the offshore wave climate. This model provides wave height, period and direction at 137 transects along the selected model domain, at a spacing of approximately 200 m. These wave conditions are then used to drive the sediment transport model. One of the particular features of the Old Bar site is the nearshore reef and Dennis shoal (figure 2), which is immediately to the north of the main erosion hotspot.

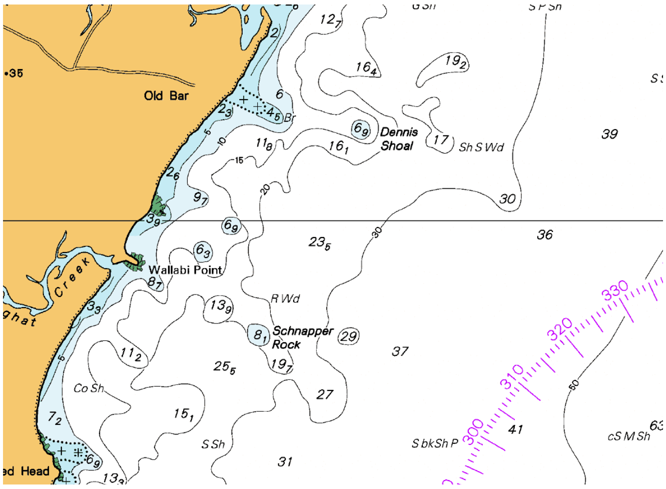

Figure 2. Bathymetry at Old Bar, NSW, showing the reef and Dennis shoal directly offshore. **NOT TO BE USED FOR NAVIGATION**. Source: Australian Hydrographic Service (see acknowledgements for copyright statement).

The offshore wave climate is determined from historical records from tide gauges, offshore wave buoys (see acknowledgements), and wave model hindcasts, which were gathered and analysed for the case study sites. Through statistical approaches (Davies et al., 2017), these historical records were recreated as synthetic time-series preserving the original hydrodynamic properties, yet allowing for storms to occur within a wide range of alternate yet realistic sequencing scenarios. Due to only short historical record being available at Old Bar, wave data from Sydney was transformed to the Old Bar site. The final synthetic offshore wave climate comprises of one thousand, 1000 year records of waves at hourly intervals, from which an expected wave climate and multiple 50 year long realisations of the same statistical wave climate can be generated.

The incident offshore waves have complex interactions with the continental shelf and nearshore bathymetry. The transformation of the offshore wave height, period and direction is unique for each nearshore transect (figure 4) along the case study beaches. The transformation is performed using a nearshore hydrodynamic wave model, SWAN (Booij, 1999), initiated at the offshore boundary of the model. For this purpose, wave lookup tables were generated through a series of stationary SWAN wave model simulations covering the full range of potential offshore wave conditions. The results from this work compared favourably with the NSW wave transformation toolbox (Taylor, 2015).

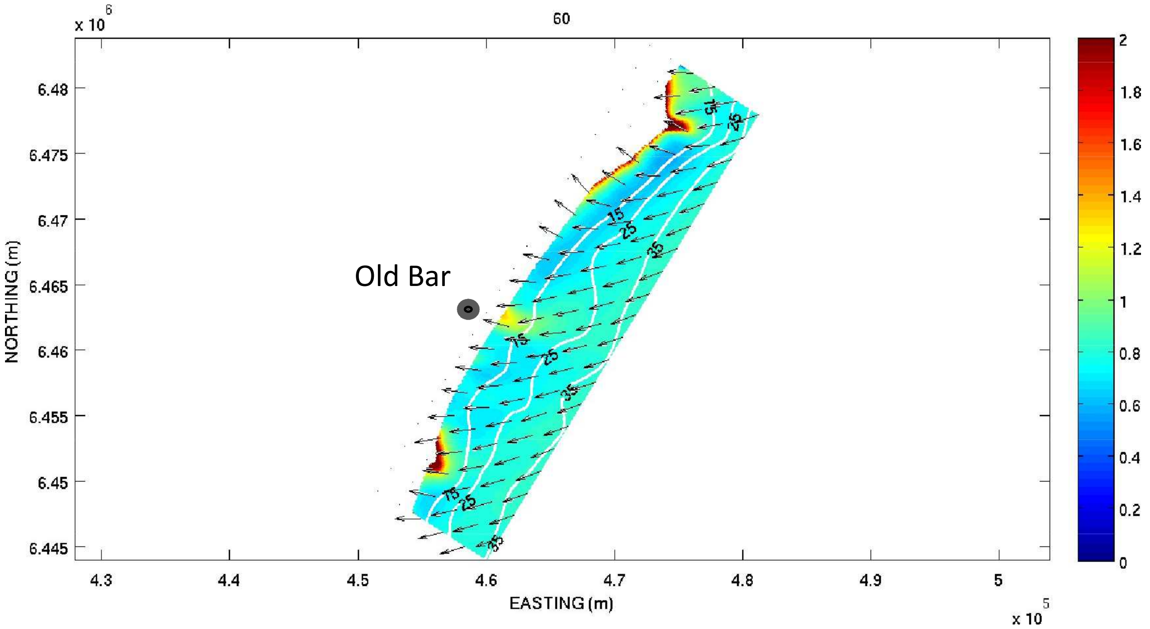

Figure 3. Example of wave transformation from offshore to nearshore for a wave with period 11s and offshore direction from 60deg N. Colours show wave height amplification.

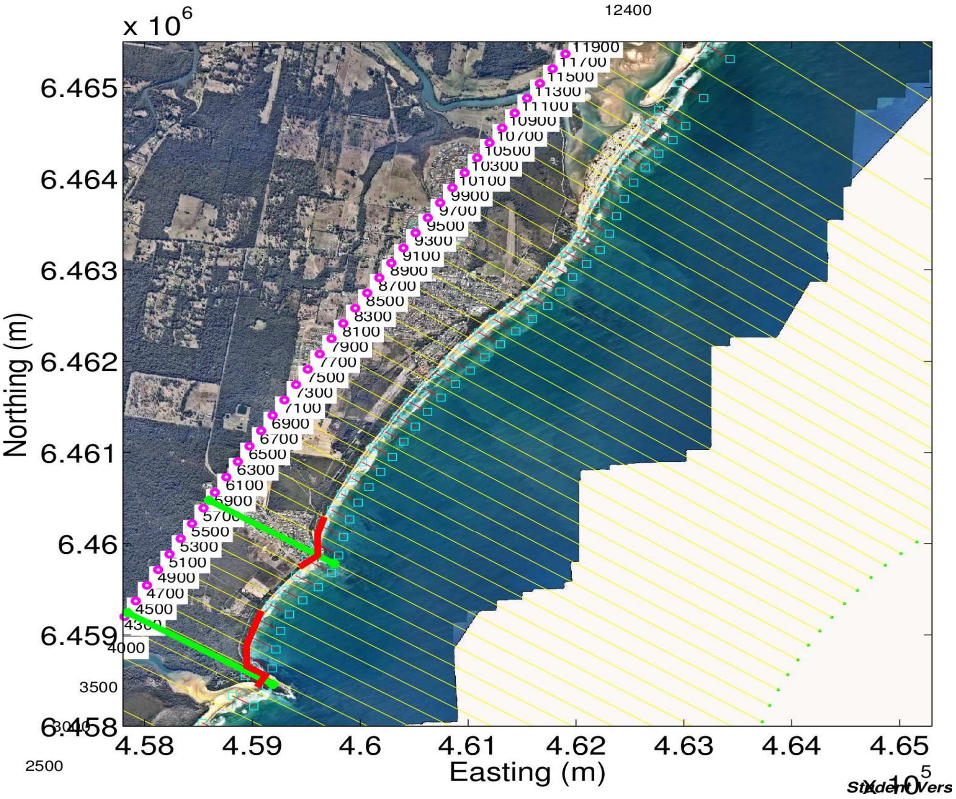

Figure 4. Model transects used for shoreline modelling at Old Bar, with sections of rocky shoreline ((red) and headlands (green) indicated. Headlands are incorporated into the modelling as barriers to longshore transport.

SHORELINE MODEL

The shoreline model is a hybrid model, based on the classical one-line model approach for longshore transport, combined with a beach profile evolution model for cross-shore transport. The project determined that the EVO model developed by BMT (Teakle, 2013) was the most appropriate (Gravois, 2016) and with the potential to be made available for future research as an open source model. A typical cross-shore profile (figure 5) responds to storm wave conditions by erosion of the upper beach and subsequent accretion under non-storm conditions. This process is manifest along the beach and is represented in the modelling by longshore sediment transport. Here, longshore transport is determined by the classical CERC formulation (*Shore Protection Manual*, 1984), which uses the breaking wave height, period and direction at each transect determined by the wave model (figure 4). The gradient in the longshore transport provides the imbalance in sediment transport that drives shoreline accretion and/or erosion. The longshore transport gradients are in turn influenced by supply of sediment at model boundaries (i.e. headlands), sediment sinks at estuary mouths, and also by small headlands and reefs that can temporarily trap sediment moving along shore. The model requires calibration to observed transport rates, which over the last 50 years at Old Bar show a general pattern of erosion (figure 6), possibly influenced by sand extraction in Harrington inlet. However, the longer term sediment balance is unknown.

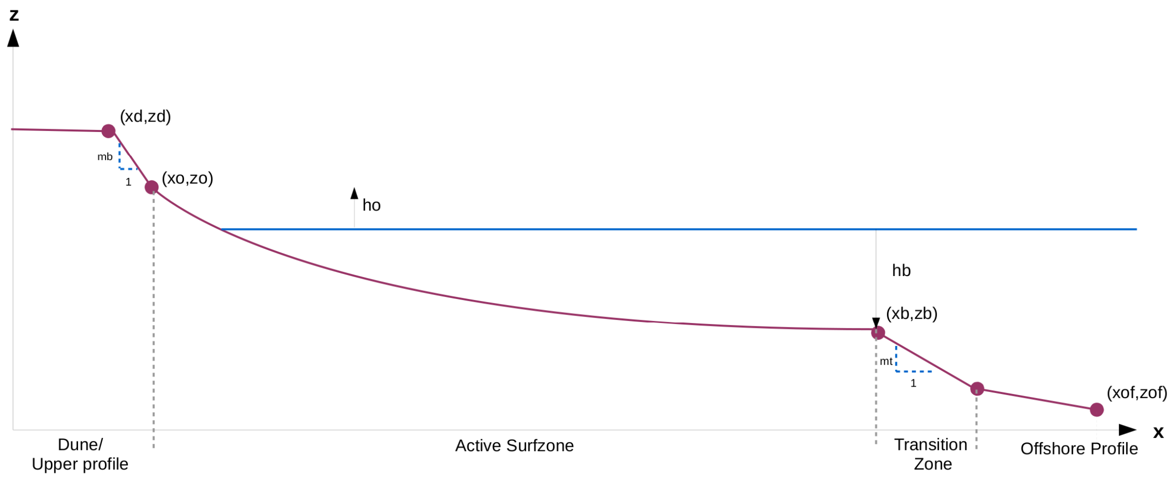

Figure 5. Beach profile for the EVO model, showing coordinate points that adjust for different wave conditions.

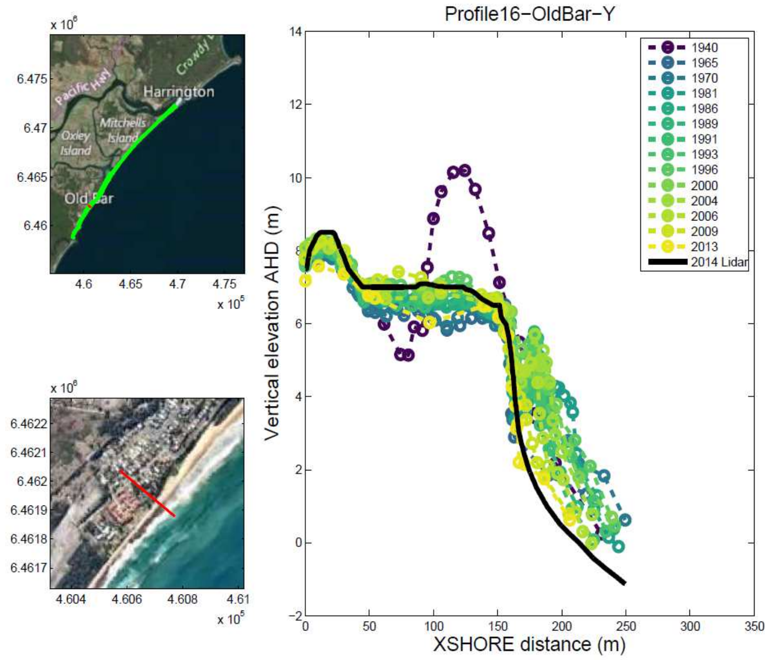

Figure 6. Dune erosion and shoreline recession at Old Bar, NSW, since 1965.

RESULTS & PRELIMINARY INTERPRETATION

An example of the shoreline movement over 50 years for one realisation of the modelled waves at Old Bar is shown in figure 7. The shoreline position oscillates over a range of 40m, with a net recession of about 20m in this case. Annual and decadal oscillations are apparent. Running many simulations with different realisations of the same statistical wave climate provides multiple predictions of the shoreline position, from which a statistical distribution can be derived. For Old Bar, this distribution indicates a wide variability in the shoreline recession or accretion and a strong sensitivity to wave climate (figure 7). This variability is interpreted to be due to Old Bar being situated at a pivot point on the longshore transport pathway, with the net sediment transport oscillating between northward and southward over decadal time frames. Hence, annual and decadal oscillations in shoreline position are predicted by the model. The results indicate that the current erosion trend may lie within an envelope of evolutionary behaviour that includes stable or accretionary phases with durations of several decades. Combining the results from thousands of model runs will provide an expected position and the most likely maximum erosion for different return periods.

CONCLUSIONS

Coastal erosion and inundation risks associated with storms, particularly for coincident or clustered events, are stochastic, requiring a probabilistic approach to assess the resilience of coastal communities in a changing climate. The dynamic nature of the shoreline, with strong feedback between response and forcing, requires simulating many realisations of statistically similar forcing conditions to calculate return periods for the maximum extent of shoreline retreat. This project is representing these processes by linking a new analysis of the wave climate with a morphodynamic model to assess the combined effects of longshore and cross-shore sediment transport on shoreline oscillations at an erosion hotspot on the NSW coast. The results suggest the current erosion trend at Old Bar may lie within an envelope of behaviour that also encompasses stable or accretionary phases of beach evolution. Having this understanding of the range of shoreline responses to storms will allow coastal managers to implement more targeted management strategies, such as establishing hazard zones that accommodate for the envelope of change. The methodology is being developed to be transferable to other locations and will be further tested at the Adelaide Metropolitan beaches.

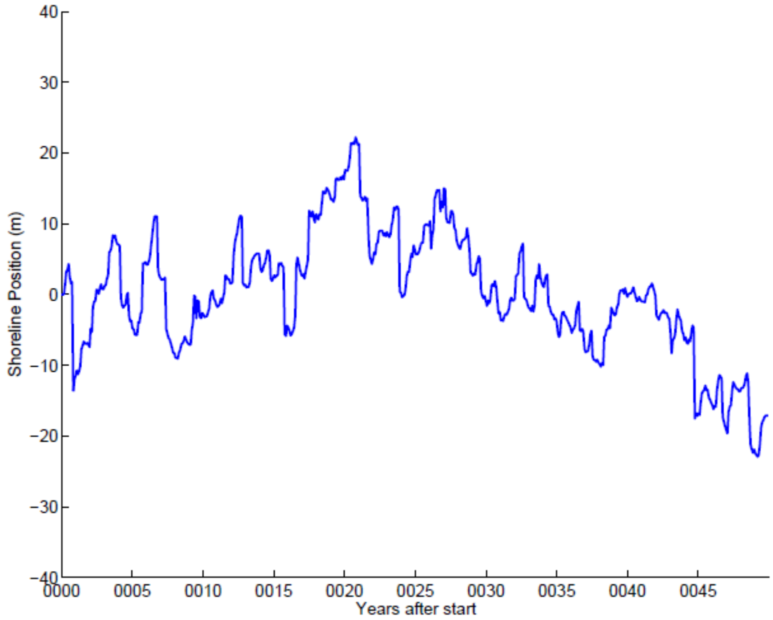

Figure 7. Example of shoreline movement over 50 years for one realisation of the modelled waves at Old Bar, NSW corresponding to location depicted in figures 1 and 6. Negative values correspond to erosion (landward motion of the shoreline).

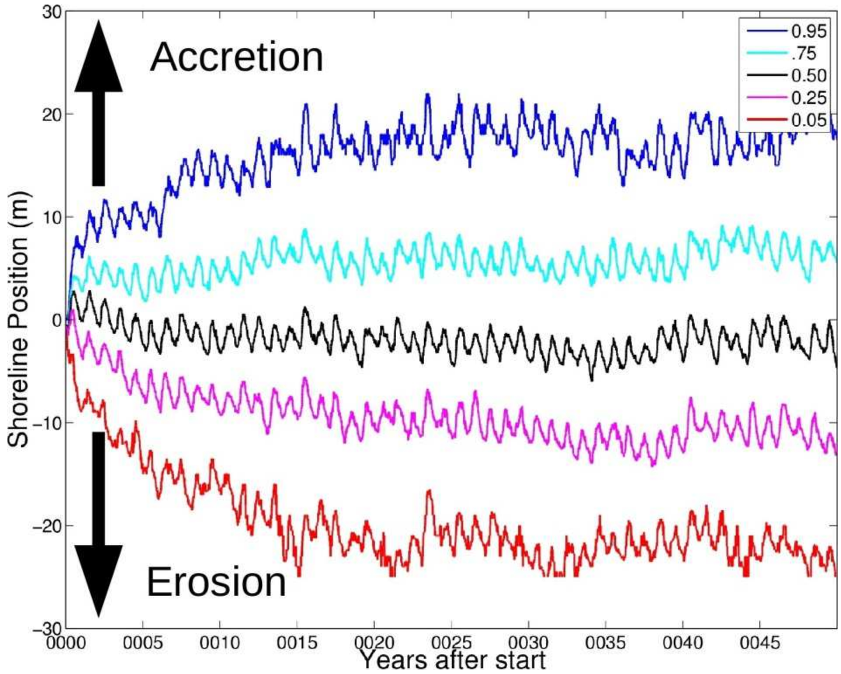

Figure 8. Results from EVO model calibration at Old Bar, NSW corresponding to location depicted in figures 1 and 6. Shown are 5%, 25%, 50%, 75% and 95% of the cumulative distribution of modelled shoreline position from 200 different synthetic forcing scenarios. For example, at a given time 10 of the 200 modelled shoreline positions were seaward (more erosive) than the red line. Negative values correspond to erosion (landward motion of the shoreline).

Acknowledgements

1) In reference to figure 2:

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2) Wave data used for this study is owned by the NSW, Office of Environment Heritage. Manly Hydraulics Laboratory was responsible for collection and provision of the data.

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